

Evaluasi Pelaksanaan Pengolahan Limbah Medis Padat Menggunakan Teknologi Sterilwave di UPT Laboratorium Kesehatan dan Lingkungan Dinas Kesehatan Provinsi Riau

Evaluation of Solid Medical Waste Treatment Implementation Using Sterilwave Technology at the Health and Environmental Laboratory Unit of the Riau Provincial Health Office

Marwad^{1*}, Oktavia Dewi², Sangap Daniel Tarigan³

^{1,2,3}Program Studi Magister Ilmu Kesehatan Masyarakat Universitas Hang Tuah Pekanbaru
Email: marwad7685@gmail.com

Abstrak

Pengelolaan limbah medis padat merupakan aspek penting dalam kesehatan lingkungan yang memerlukan penanganan tepat untuk mencegah pencemaran lingkungan dan melindungi kesehatan masyarakat. Unit Pelaksana Teknis Laboratorium Kesehatan dan Lingkungan (UPT Labkesling) Provinsi Riau telah menerapkan teknologi Sterilwave, yaitu sistem pengolahan limbah berbasis gelombang mikro, sebagai alternatif terhadap metode insinerasi konvensional, namun dalam pelaksanaannya masih menghadapi berbagai tantangan operasional. Penelitian ini bertujuan untuk mengevaluasi pelaksanaan pengolahan limbah medis padat menggunakan teknologi Sterilwave serta mengidentifikasi faktor-faktor yang memengaruhi efektivitasnya. Penelitian menggunakan pendekatan kualitatif dengan desain studi kasus dan metode problem solving cycle. Pengumpulan data dilakukan melalui observasi, wawancara mendalam, dan telaah dokumentasi pada bulan Oktober 2025, kemudian dianalisis menggunakan diagram fishbone dan metode USG (Urgency, Seriousness, Growth) untuk menentukan prioritas masalah. Hasil penelitian menunjukkan lima permasalahan utama dengan prioritas pada belum optimalnya proses pengolahan limbah medis padat menggunakan teknologi Sterilwave, yang disebabkan oleh faktor sumber daya manusia, metode, material, mesin, pendanaan, dan lingkungan. Solusi yang direkomendasikan adalah kombinasi pendekatan soft berupa peningkatan kapasitas melalui pelatihan dan supervisi serta pendekatan hard berupa penyediaan sarana pendukung seperti sistem kalibrasi, stabilizer, dan ventilasi mekanik. Strategi ini dinilai efektif dan efisien karena dapat dilaksanakan dengan sumber daya yang tersedia tanpa memerlukan investasi besar serta berpotensi berkelanjutan dalam menjaga efektivitas dan keamanan pengolahan limbah medis padat.

Kata kunci: Pengelolaan Limbah Medis, Sterilwave, Sterilisasi Gelombang Mikro, Laboratorium Kesehatan Lingkungan.

Abstract

Solid medical waste management is a critical aspect of environmental health that requires proper handling to prevent environmental contamination and protect public health. The Environmental Health Laboratory Unit (UPT Labkesling) of Riau Province has implemented Sterilwave technology, a modern microwave-based waste treatment system, as an alternative to conventional incineration. However, the implementation still faces several operational challenges. This study aims to evaluate the implementation of solid medical waste treatment using Sterilwave technology and identify factors affecting its effectiveness. The research employed a qualitative approach with a case study design and problem-solving cycle method. Data collection was conducted through observation, in-depth interviews, and documentation during October 2025. Analysis used fishbone diagrams and the USG (Urgency, Seriousness, Growth) method to determine problem priorities. The study identified five main problems, with priority given to the suboptimal process of solid medical waste treatment using Sterilwave. Fishbone analysis revealed that problem causes originated from six factors: human resources, methods, materials, machines, funds, and environment. The recommended solution is a combination of soft approaches (capacity building through training and supervision) and hard approaches (provision of supporting facilities such as calibration systems, stabilizers, and mechanical ventilation). This strategy is considered effective and efficient because it can be implemented with existing resources without major investment and has potential for long-term sustainability in maintaining treatment effectiveness and safety.

Keywords: Medical Waste Management, Sterilwave, Microwave Sterilization, Environmental Health Laboratory

*Corresponding Author: Marwad, Universitas Hang Tuah Pekanbaru, Riau, Indonesia

E-mail : marwad7685@gmail.com

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1. INTRODUCTION

The Technical Implementation Unit (UPT) of the Health and Environmental Laboratory of the Riau Provincial Health Office is a technical institution that plays a strategic role in supporting environmental preservation and improving environmental health quality. As a provincial reference laboratory, UPT Labkesling is committed to ensuring that all analytical processes are carried out in accordance with applicable operational standards and regulations to guarantee the accuracy and reliability of test results [1]. Solid medical waste is a category of hazardous waste generated by healthcare facilities, including laboratories, which poses significant risks due to the presence of infectious agents, hazardous chemicals, and sharp objects that may endanger human health and pollute the environment [2]. To address these risks, the Indonesian government has established regulations related to medical waste management, including the Regulation of the Minister of Health Number 18 of 2020 on Medical Waste Management in Healthcare Facilities and the Regulation of the Minister of Environment and Forestry Number P.56/MENLHK-Setjen/2015 [3]. One technological innovation in medical waste treatment is Sterilwave, a microwave-based system that sterilizes and destroys waste simultaneously without a combustion process, making it more environmentally friendly than incineration due to the absence of harmful emissions such as dioxins and furans, while also reducing waste volume by up to 80% and rendering it non-infectious [4]. Although Sterilwave technology has been implemented at UPT Labkesling of Riau Province, several challenges remain, including limited operator understanding, suboptimal routine maintenance, and insufficient systematic monitoring; therefore, this study aims to evaluate the implementation of solid medical waste treatment using Sterilwave technology at UPT Labkesling of the Riau Provincial Health Office.

The effective implementation of medical waste treatment technology is essential to reduce health risks and environmental impacts associated with hazardous healthcare waste. Previous studies have demonstrated that non-incineration technologies, including microwave-based treatment systems, are effective in inactivating pathogens while minimizing harmful emissions compared to conventional incineration methods [5]. However, the success of such technologies is not solely determined by equipment performance, but also by the competence of human resources, adherence to standard operating procedures, and the availability of systematic monitoring and maintenance programs [6]. Continuous evaluation of medical waste management systems is therefore necessary to ensure operational effectiveness, regulatory compliance, and long-term sustainability of healthcare waste treatment facilities [7].

2. METHODOLOGY

Type and Research Design

This study employed a qualitative research approach with a case study design. The research was conducted using a problem-solving cycle framework to systematically evaluate the implementation of solid medical waste treatment using Sterilwave technology. This design was chosen to obtain an in-depth understanding of operational practices, challenges, and contextual factors influencing the effectiveness of waste management at the study site.

Research Location and Period

The study was conducted at the Technical Implementation Unit (UPT) of the Health and Environmental Laboratory (Labkesling) of the Riau Provincial Health Office, located in Pekanbaru, Riau Province, Indonesia. Data collection was carried out from October 13 to October 30, 2025.

Population and Sample

The study population consisted of stakeholders involved in solid medical waste management at UPT Labkesling. Informants were selected using a purposive sampling technique based on their roles and relevance to the Sterilwave waste treatment process. Key informants included Sterilwave operators, laboratory analysts, and the Head of the Laboratory, while supporting informants comprised cleaning service personnel and maintenance technicians.

Data Analysis Method

Data were collected through direct observation, in-depth interviews, and document review. Qualitative data were analyzed thematically to identify patterns related to implementation challenges. Root cause analysis was conducted using a fishbone (Ishikawa) diagram, while problem prioritization was determined using the USG (Urgency, Seriousness, and Growth) method. Descriptive quantitative data were presented in tables and figures to support qualitative findings. Data validity was ensured through source and method triangulation.

3. RESULTS

Overview of the Research Location

The Riau Province Health and Environmental Laboratory Unit is located at Jalan Mustika No. 3A, Pekanbaru, within the Arifin Ahmad Regional General Hospital complex. The laboratory's vision is "To establish a professional testing laboratory that excels in performance and meets international standards." The laboratory's mission includes providing professional services, implementing a consistent quality management system, enhancing competency-based testing capabilities, and developing science and technology.

Situation Analysis and Problem Identification

Based on observations and interviews, five main problems were identified:

Table 1. Identification of problems

No	Problem	Reason	Impact
1	Processing with the Sterilwave device is not routinely carried out	There is no schedule for equipment use	Solid waste accumulates in temporary storage areas
2	Management of laboratory electronic waste (e-waste) does not meet standards	SOPs for handling electronic waste have not been implemented	Heavy metal contamination (Pb, Hg, Cd) in soil and water
3	Placement of chemicals that have been removed from the storage warehouse does not meet standards	No labeling and separation based on material characteristics	Risk of chemical reactions, fires, or explosions
4	Laboratory waste is mixed with medical and non-medical waste	Lack of sorting at source before processing	Risk of contamination to laboratory personnel
5	Chemical spill handling does not follow procedures	Emergency response equipment and adequate personal protective equipment have not been provided	Direct exposure to toxic materials

Determining Problem Priorities

Using the ultrasound method with a 1-5 rating scale, the following results were obtained:

Table 2. Determining Problem Priorities

No	Problem	U	S	G	Score	Ranking
1	The solid medical waste treatment process using Sterilwave is not optimal	5	5	5	15	1
2	Management of laboratory electronic waste (e-waste) does not meet standards	4	5	4	13	2
3	Placement of chemicals that have been removed from the storage warehouse does not meet standards	4	4	4	12	3
4	Laboratory waste is mixed with medical and non-medical waste	4	4	3	11	4
5	Handling of chemical spills does not follow procedures	3	3	3	9	5

Based on the assessment results, the priority problem is "The solid medical waste processing process with Sterilwave is not optimal" with the highest score (15).

Root Cause Analysis of the Problem

Using a fishbone diagram with the 6M approach (Man, Method, Material, Machine, Money, Environment), various root causes of the problem were identified. From the human aspect, it was found that operators only received initial

training during the equipment function test, without any follow-up programs or regular skills refreshers. This resulted in limited technical knowledge for operators, particularly regarding maintenance and monitoring of sterilization effectiveness. Furthermore, the lack of consistent monitoring of sterilization duration and the high workload due to staff having multiple duties in other laboratory areas exacerbated the situation. Inconsistent internal oversight and weak inter-divisional coordination also hampered waste management.

From the method aspect, it was found that the SOP for equipment operation and maintenance was poorly communicated to all relevant personnel. The lack of a routine checklist for pre- and post-sterilization inspections resulted in poorly documented monitoring. Procedures for monitoring sterilization effectiveness through biological or chemical indicator tests were also not routinely implemented. Documentation of sterilization results was still done manually and did not use a standard, systematic format, complicating evaluation and the absence of routine process performance evaluation. The material aspect shows that solid medical waste is often mixed with non-medical waste before being fed into the Sterilwave device due to the lack of a pre-sorting stage. Some types of waste, such as thick rubber, can hinder the operation of the device's shredder blades, but there are no clear restrictions regarding the types of waste that can be processed. Sorting staff also lack understanding of medical waste classification, and there are no technical instructions (juknis) on proper sorting procedures.

From the machine aspect, equipment calibration has not been carried out regularly due to the lack of ongoing collaboration with an accredited calibration institution. Temperature and pressure sensors are not continuously monitored, and there is no automatic alarm system in the event of process failure because the device's warning feature is not activated or is not functioning. Some machine components, such as the shredder blades, have experienced wear but have not been replaced, as equipment maintenance remains reactive after damage occurs, rather than preventative.

The financial aspect shows that the maintenance and calibration budget is limited because the annual budget planning does not specifically include the maintenance needs of the Sterilwave device. The lack of a dedicated budget for operator training and funding for external monitoring of sterilization effectiveness hinders quality improvement. High electricity costs are not offset by adequate operational support, and spare parts procurement is often delayed due to limited funding and lengthy administrative procedures.

Finally, from an environmental perspective, the cramped and densely packed waste processing area restricts air circulation and staff movement. Placing equipment close to clean areas, such as the canteen, increases the risk of cross-contamination due to the lack of clear separation zones. The availability of an unstable power source, with frequently fluctuating voltage, can disrupt the sterilization process, which requires constant temperature and pressure. The environment around the equipment is also less than clean because work areas are not cleaned regularly and there is no separation between dirty and clean areas.

Alternative Problem-Solving

Based on the root cause analysis, alternative solutions are developed for each factor:

Table 3. Alternative Problem Solving

No	Factor	Reason	Alternative Solutions
1	Man	Poorly trained operators, high workload, weak supervision	Regular advanced training, additional staff, periodic supervision system, enforcement of work discipline
2	Method	SOPs not socialized, no checklists, irregular monitoring	Preparation and dissemination of SOPs, creation of standard checklists, integrated monitoring schedules, routine training
3	Material	Mixed waste, no pre-sorting	Waste sorting training, provision of labeled containers, development of sorting technical guidelines, supervision at source
4	Machine	No calibration, reactive maintenance, unmonitored sensors	Periodic calibration schedule, preventive maintenance SOP, automatic monitoring system, replacement of worn components
5	Money	Limited budget, no funding for training and	Preparation of

		monitoring	comprehensive RKA, allocation of special items, cost sharing with other parties, budget prioritization
6	Environment	Cramped space, unstable electricity, no zoning	Redesign of room layout, installation of stabilizers/UPS, zone separation, mechanical ventilation system

Selecting the Best Solution and Intervention Plan

Based on considerations of effectiveness, efficiency, resource availability, and sustainability, priority solutions were selected that combine soft (human resource capacity building) and hard (supporting facility provision) approaches:

1. Soft Approach:

- Advanced technical training and periodic refresher training for operators
- Development and implementation of detailed and integrated SOPs
- Formation of an internal audit team
- Reward system for SOP compliance

2. Hard Approach:

- Establishment of a routine calibration schedule with an accredited institution
- Procurement of temperature and pressure monitoring equipment
- Installation of a stabilizer or UPS for electricity
- Provision of labeled sorting containers at each waste source
- Improvement of the layout and ventilation system of the processing room

Table 3. Intervention Plan (Plan of Action)

No	Activity	Objective	Time	Success Indicators
1	Advanced training on Sterilwave use and maintenance	Improving operator competency	2x/year	Operators are able to operate the equipment independently and safely. Equipment operations run smoothly without delay. Audit reports and follow-up are available. Regular budgets for maintenance and training are available. Calibration certificates are available and the equipment is functioning optimally. Waste is separated according to category. Digital data and routine checklists are available.
2	Addition and division of staff duties	Reducing workload	Every year	
3	Development of internal inspection and audit schedules	Ensuring SOP consistency	3 months/once	
4	Development of annual budget plans	Ensuring funding availability	Every year	
5	Periodic equipment calibration and maintenance	Maintaining optimal performance	2x/year	
6	Waste sorting awareness and training	Improving sorting quality	6 months/once	
7	Digitalization of sterilization results recording	Improving documentation accuracy	Each month	

4. DISCUSSION

1. Human Factors (Man).

Limited operator competency represents a major constraint in the operation of Sterilwave technology. Employee performance is strongly influenced by individual ability and motivation, which directly affect compliance with standard operating procedures (SOPs) [8]. Previous studies reported that personnel who routinely participate in training demonstrate significantly higher adherence to SOPs and safer work practices [9]. In addition, excessive workload has been shown to reduce concentration and increase the likelihood of human error, thereby compromising sterilization effectiveness and occupational safety [10].

2. Method Factors (Method).

Weak implementation of SOPs and inadequate documentation systems contribute to inconsistencies in waste treatment processes. The effectiveness of a work system is largely determined by the clarity and applicability of procedures [11]. The World Health Organization emphasizes that sterilization outcomes must be routinely verified using biological indicators to ensure process reliability [12]. Facilities that conduct regular biological testing have been reported to achieve significantly higher sterilization effectiveness compared to those that do not [13].

3. Material Factors.

Improper segregation of medical and non-medical waste reduces the efficiency of the Sterilwave sterilization process. Source segregation is a critical determinant of successful medical waste management and sterilization [12]. Indonesian regulations mandate waste segregation by category to prevent cross-contamination and treatment failure [14]. Studies indicate that the implementation of a color-coded segregation system can substantially reduce mixed waste volumes and improve treatment efficiency [15].

4. Machine Factors.

The absence of routine calibration and preventive maintenance negatively affects equipment reliability and treatment outcomes. Machinery reliability is closely linked to the implementation of structured preventive maintenance strategies [16]. Facilities that rely primarily on corrective maintenance exhibit significantly lower operational reliability [17]. Furthermore, international standards require temperature validation and performance monitoring to ensure the effectiveness of sterilization processes [18].

5. Money Factors.

Limited budget allocation constrains regular maintenance, calibration, and capacity-building activities. Investment in human resources and supporting systems is essential to improving organizational productivity and operational performance [19]. Evidence shows that facilities lacking annual calibration schedules experience higher rates of sterilization failure, posing risks to environmental and occupational health [20].

6. Environmental Factors.

Non-compliant work environments reduce both effectiveness and safety in medical waste treatment operations. A safe and well-designed work environment is a key determinant of productivity and process reliability [21]. National regulations stipulate minimum space requirements and the use of mechanical ventilation in waste processing areas to control temperature and exposure risks [22]. Poor layout design and inadequate ventilation have been associated with increased ambient temperatures and decreased worker productivity [23].

5. CONCLUSION

This study identified five key problems in solid medical waste processing at the Riau Province Health Laboratory Technical Implementation Unit (UPT Labkesling), prioritizing the suboptimal Sterilwave processing process. A fishbone analysis revealed six contributing factors: human resources (limited training and high workloads), methods (unsocialized SOPs and irregular monitoring), materials (mixed waste and lack of pre-sorting), machines (no periodic calibration and reactive maintenance), funding (limited budget for maintenance and training), and the environment (cramped space, unstable electricity, and no zoning).

The recommended solution is a combination of soft approaches (capacity building through training and supervision) and hard approaches (provision of facilities such as calibration systems, electrical stabilizers, and mechanical ventilation). This strategy is effective and efficient because it can be implemented with existing resources without significant investment and has the potential for long-term sustainability.

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